Claims

[Claim 1] A diffractive optical element (DOE) for diverging an incident laser beam into K diffracted beams, the k-th beam having angles (α_k, β_k) to an incident beam axis, comprising:

R×S lengthwise and crosswise aligning pixels $\{C_{mn}\}$ (m=1, 2, ..., R; n=1, 2, ..., S) of a size of a×b which have g (=2^s: s: integer) different values of thickness $\{d_{mn}\}$ varying within one wavelength of laser light λ and have g (=2^s: s: integer) different values of complex amplitude transmittance $\{t_{mn}\}$ given by $t_{mn}=\exp(j2\pi(n-1)d_{mn}/\lambda)$ where n is a diffractive index of the DOE,

the R×S pixels lacking a structure of repeating a common unit pattern and each of the R×S pixels being assigned with arbitrary $\{t_{mn}\}$ values without restrictions from $\{t_{mn}\}$ of other pixels,

the angles (α_k, β_k) of the k-th diffracted beam (k=1, 2, ..., K) satisfying equations,

$\sin\alpha_k=m_kU$,

$\sin\beta_k=n_kV$,

where m_k and n_k are integers having no common divisor, and U and V are the positive greatest common divisors (measures) for $\{\sin\alpha_k\}$ and $\{\sin\beta_k\}$ for k=1, 2, ..., K, and

both or either of the greatest common divisors U and V being smaller than a quotient λ/aR or λ/bS of the laser wavelength λ divided by a size aR or bS of the DOE, that is,

$U<\lambda/aR$,

$V<\lambda/bS$.

[Claim 2] A diffractive optical element (DOE) comprising:

R×S lengthwise and crosswise aligning pixels $\{C_{mn}\}$ (m=1, 2, ..., R; n=1, 2, ..., S) of a size of a×b which have g (=2^s: s: integer) different values of thicknesses $\{d_{mn}\}$ varying within one wavelength of laser light λ and have g (=2^s: s: integer) different values of complex amplitude transmittance $\{t_{mn}\}$ given by $t_{mn}=\exp(j2\pi(n-1)d_{mn}/\lambda)$ where n is a diffractive index of the DOE,

complex amplitude $W(\alpha, \beta)$ of a beam diffracted in a direction of a horizontal angle α and a vertical angle β being calculated not by the Fast Fourier Transform but by,

$$W(\alpha, \beta) = \mathrm{sinc}\left(\frac{a\alpha}{\lambda}\right)\mathrm{sinc}\left(\frac{b\beta}{\lambda}\right)\sum_m \sum_n t_{mn} \exp\{-jk(ma\alpha + nb\beta)\}$$

where summations are carried out for all the pixels in the DOE and some or all of the diffraction beam angles (α, β) are either on or off lattice points defined on an object plane,

in the case of diverging an incident laser beam into K diffracted beams, the k-th beam having angles (α_k, β_k) to an incident beam axis,

the angles (α_k, β_k) of the k-th diffracted beam (k=1, 2, …, K) satisfying equations,

$\sin\alpha_k = m_k U$,

$\sin\beta_k = n_k V$,

where m_k and n_k are integers having no common divisor and U and V are the positive greatest common divisors (measures) for $\{\sin\alpha_k\}$ and $\{\sin\beta_k\}$ for k=1, 2, …, K, and

both or either of the greatest common divisors U and V being smaller than a quotient λ/aR or λ/bS of the laser wavelength λ divided by a size aR or bS of the DOE, that is,

$U < \lambda/aR$,

$V < \lambda/bS$.

[Claim 3] The diffractive optical element according to claim 1 or claim 2, wherein the DOE is a Fraunhofer type DOE having an infinitely long focal length ($f=\infty$ or $f=-\infty$).

[Claim 4] The diffractive optical element according to claim 1 or claim 2, wherein the DOE is a Fresnel type DOE having a finite focal length (($-\infty < f < \infty$).

[Claim 5] The diffractive optical element according to claim 1, wherein calculations of diffracted beam intensity are not based upon the Fast Fourier Transform but carried out by summing the whole terms of all the pixels.

[Claim 6] The diffractive optical element according to any one of claims 1 to 5, wherein

calculations of diffracted beam intensity are carried out by summing the whole terms of all the pixels and calculations of noise are carried out the Fast Fourier Transform for alleviating noise calculation time, and the transmittance distribution $\{t_{mn}\}$ is determined for satisfying a restriction of desired diffraction beam intensity and another restriction of reduction of noise.

[Claim 7] A laser machining apparatus comprising:

a laser apparatus for producing a laser beam;

a diffractive optical element (DOE) for diverging the laser beam into K diffracted beams, the k-th beam having angles (α_k, β_k) to an incident beam axis, comprising

R×S lengthwise and crosswise aligning pixels $\{C_{mn}\}$ (m=1, 2, ..., R; n=1, 2, ..., S) of a size of a×b which have g ($=2^s$: s: integer) different values of thickness $\{d_{mn}\}$ varying within one wavelength of laser light λ and have g ($=2^s$: s: integer) different values of complex amplitude transmittance $\{t_{mn}\}$ given by $t_{mn}=\exp(j2\pi(n-1)d_{mn}/\lambda)$ where n is a diffractive index of the DOE,

the R×S pixels lacking a structure of repeating a common unit pattern,

each of the R×S pixels being assigned with arbitrary $\{t_{mn}\}$ values without restrictions from $\{t_{mn}\}$ of other pixels,

the angles (α_k, β_k) of the k-th diffracted beam (k=1, 2, ..., K) satisfying equations,

$\sin\alpha_k = m_k U$,

$\sin\beta_k = n_k V$,

where m_k and n_k are integers having no common divisor, and U and V are the positive greatest common divisors (measures) for $\{\sin\alpha_k\}$ and $\{\sin\beta_k\}$ for k=1, 2, ..., K, and

both or either of the greatest common divisors U and V being smaller than a quotient λ/aR or λ/bS of the laser wavelength λ divided by a size aR or bS of the DOE, that is,

$U<\lambda/aR$,

$V<\lambda/bS$; and

a lens for converging the diffracted beams on a plurality of aimed points on an object.

[Claim 8] The laser machining apparatus according to claim 7, wherein the converging lens is an fsinθ lens.